

HEAVY METAL CONTENT IN OTOLITHS OF KING MACKEREL (*SCOMBEROMORUS CAVALLA*) IN RELATION TO BODY LENGTH AND AGE

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ABSTRACT

The maximum concentrations of heavy metals (zinc, cadmium, copper, and lead) in otoliths of king mackerel (*Scomberomorus cavalla*) were found in very young fish. The apparent decline in content of metals with age and length in king mackerel otoliths most approximated a negative power curve ($y = ax^{-b}$). The zinc content of otoliths was found to vary significantly between areas in the southeast U.S. and with the age of the fish.

INTRODUCTION

A considerable amount of information is available on the metal content in the soft tissue and skeletal structure of teleost fishes (for example, Vinogradov 1953; Hall, Zook and Meaburn 1978; Meaburn 1979), but only in recent years have the heavy metal contents in otoliths and their relationships to body length or age been investigated (Papadopolou, Kanas and Moraitopoulou-Kassimati 1976, 1978, 1980; Macpherson and Manriquez 1977; Gauldie and Nathan 1977). Widespread interest in otoliths developed after Reibisch (1899) found that the age of fish could be approximated from the number of rings deposited in the otolith. Subsequent research on otoliths of the Teleostei has established their composition as aragonite, a polymorph of calcium carbonate, and a protein matrix. These substances are deposited in thin layers to form the growth zones that make up a chronological record of growth (Immerman 1908; Dannevig 1956; Degens, Deuser and Haedrich 1969; Pannella 1971). Investigations of the occurrence of heavy metals in otoliths are of particular interest, as otoliths remain essentially insulated concretions in the labyrinth during the life of the fish. These concretions are made of materials that are successively deposited but not removed by physiological processes (Mugiya 1964, 1974; Simkiss, 1974).

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Papadopoulou *et al.* (1976) working on the zinc content of otoliths of chub mackerel (*Scomber japonicus colias*) in the age classes from zero to six years concluded that the concentration of zinc in the otoliths was a linear function of the age and body length of the fish. In a later study, Papadopoulou *et al.* (1980) found cesium, cobalt, iron, selenium and silver in otoliths of chub mackerel. They found that these metals generally decrease in concentration with the age of the fish. Macpherson and Manriquez (1977) analyzed the metal concentration in otoliths of stockfish (*Merluccius capensis*) and determined that strontium along with calcium, sodium, magnesium, and potassium appeared in constant quantity (increased with otolith weight) and that iron, copper, and vanadium only appeared in a few samples and therefore were contaminants. No attempt was made by them to relate the heavy metal concentration to the age of the fish. Gauldie and Nathan (1977) examined otoliths of tarakihi (*Cheilodactylus macropterus*) from New Zealand waters for possible contaminants from the extensive volcanic activity in the area but found only traces of zinc, copper, cadmium, nickel, and manganese. However, iron occurred in concentrations up to 7 μg per otolith, and the otolith could be placed in three groups by iron content. These groups corresponded to the three major fishing grounds of New Zealand. They found no significant increase in the iron concentration with the age of the fish. In further work on the tarakihi, Gauldie, Graynoth and Illingworth (1980) demonstrated that the iron content showed a positive regression on environmental temperature.

The objectives of our study were to determine the concentrations of copper, cadmium, zinc, and lead in otoliths of king mackerel (*Scomberomorus cavalla*) from the U.S. Atlantic and Gulf of Mexico and to determine their relation to length and age of the fish and if geographic differences could be observed. King mackerel is a migratory species important to commercial and recreational fisheries in the Gulf of Mexico and along the Atlantic seaboard of the United States (Nakamura and Bullis 1979).

METHODS

Otoliths (sagittae) were removed from 89 fresh king mackerel of known fork length (FL in mm). The fish were caught in the latter half of 1978 off Corpus Christi, Texas (15 fish), Grand Isle, Louisiana (20 fish), Panama City, Florida (33 fish), and Beaufort, North Carolina (21 fish). The otoliths were carefully cleaned and stored dry in vials.

Prior to analysis, the otoliths were immersed in glycerol (for 10-20 sec) to enhance the appearance of the growth rings for age determination. The age in years of the fish was determined by counting the number of opaque rings following the method of Johnson, Fable, Williams and Barger (1983). For metal analyses the otoliths were soaked and rinsed five or more times in hot, deionized, 18-megohm water to remove the glycerol. The otoliths were then weighed, placed with 1 ml of concentrated nitric acid in acid cleaned cylinders and allowed to dissolve for 16 h at room temperature. Nine milliliters of water were added to bring the volume of the solution to 10 ml. The zinc concentration of the otolith was determined by flame atomic absorption spectrophotometry (Emmel, Stoer and Stux 1977) using an Instrumentation Laboratory Spectrophotometer, Model No. 751⁴. The cadmium, copper, and lead concentration of the otoliths were determined by the following procedure:

⁴ References to trade names do not constitute endorsement by the National Marine Fisheries Service, NOAA

- 1) an aliquot of the dissolved otolith was pipetted into acid treated digestion tubes;
- 2) one milliliter of a digestion acid mixture (HClO_4 , HNO_3 , H_2SO_4 in the ratio of 24:24:1) was added to each tube and heated to near dryness;
- 3) five milliliters of 1.0 M sodium acetate - 0.2 M sodium chloride buffer were added;
- 4) the concentrations of the metals were determined by anodic stripping voltammetry⁵.

Detection limits for zinc, cadmium, copper, and lead were 1.0, 0.01, 0.05 and 0.05 $\mu\text{g/g}$, respectively, based on an otolith of 0.05 g weight. The glycerol (a single batch of No. G-7757 Sigma Chemical Company) was analyzed by the same techniques as the otoliths and found to be free of heavy metals.

RESULTS AND DISCUSSION

Obtaining representative samples of all ages and sizes of fish from various locations was difficult for king mackerel because this species is highly migratory and different fishing gear types were used, which select different sizes of fish, in different areas. Trent, Williams, Taylor, Saloman and Manooch (1983) reported on the high level of geographic variation of king mackerel sizes in the southeastern U.S.

The relationship between years (X) and fork length (Y as millimeters) can be described by the equation $Y = 598.57 + 63.0914X$ with a correlation coefficient (r) equal to $+ 0.9770$ for the fish used in this study.

The heavy metal content in king mackerel otoliths varied between location and age (Table 1). Heavy metal content in king mackerel otoliths were generally highest in the first two years (fish less than 835 mm FL) (Table 1). The greatest concentration of zinc (49.7 $\mu\text{g/g}$) and copper (41.4 $\mu\text{g/g}$) in an otolith occurred in fish of age 0+ (fish less than 500 mm FL). The greatest concentrations of lead (15.1 $\mu\text{g/g}$ and cadmium (9.38 $\mu\text{g/g}$) were found in fish of age 1+.

Examination of the data (Table 1) using multifactor ANOVA (Anonymous 1986) comparing location, age, and metal content indicated that only zinc content varied significantly ($P < 0.05$) between location and age ($P = 0.0261$ and $P = 0.0003$). We thus consider that while there appears to be relationships between metal contents and age, additional sampling is needed to confirm these observations.

The range of zinc concentration in otoliths of king mackerel (below detection limit to 49.7 $\mu\text{g/g}$) was noticeably lower than in those of chub mackerel 7 to 70 $\mu\text{g/g}$) (Papadopoulou *et al.* 1976). Papadopoulou *et al.* (1976) stated that the zinc concentration of otoliths was a negative linear function of age and growth of chub mackerel. They pointed out that the zinc concentration in the young and small fish under three years, was double that in otoliths of mature fish. In king mackerel, however, the zinc concentration of the otoliths was not linearly related to age and length. However, the relationship between age and growth and otolith zinc content was not well represented by either linear or negative power curve equations ($Y = 3.96 - 0.003X$, $r = -.57$ and $Y = 168.8X^{-.43}$, $r = -.59$).

A negative power curve ($y = ax^{-b}$) was found to approximate the apparent decline of the metal concentrations in the otoliths with growth in king

⁵ Environmental Science Associates, unpublished procedure.

TABLE 1

Mean total weight and metal content of king mackerel otoliths by location and age.

Location	FL (mm) X	Age (yrs)	No. of fish	Otolith		Metal Content (micro-grams)							
				Weight X	(g) SD	Zinc		Copper		Cadmium		Lead	
						X	SD	X	SD	X	SD	X	SD
Texas	632.5	1	2	0.02	0.01	0.38	0.04	0.13	0.10	0.08	0.11	0.13	0.13
Texas	763.3	2	3	0.03	0.01	0.49	0.32	0.11	0.10	0.01	X ¹	0.08	0.04
Texas	780.7	3	4	0.03	X	0.56	0.15	0.25	0.34	X	0.01	0.03	0.03
Texas	-----	5	1	0.06	- ²	0.62	-	0.02	-	ND ³	-	0.01	-
Texas	976.3	6	4	0.06	X	0.87	1.00	0.06	0.02	ND	-	0.01	0.01
Texas	935.0	8	1	0.06	-	0.75	-	0.06	-	ND	-	ND	-
Louisiana	910.0	2	1	0.04	-	0.49	-	0.03	-	ND	-	ND	-
Louisiana	994.8	4	2	0.06	X	0.50	0.42	0.14	0.15	ND	-	0.01	X
Louisiana	1,028.0	5	4	0.06	X	0.62	0.01	0.02	X	ND	-	0.01	X
Louisiana	1,111.5	6	3	0.06	X	0.65	0.27	0.08	0.08	ND	-	ND	-
Louisiana	1,173.7	7	3	0.08	0.01	0.73	0.10	0.10	0.14	ND	-	0.02	0.03
Louisiana	1,070.0	9	1	0.08	-	0.70	-	0.03	-	ND	-	ND	-
Louisiana	1,399.0	10	1	0.11	-	0.85	-	0.10	-	ND	-	ND	-
Louisiana	1,350.5	12	3	0.11	X	1.74	1.46	0.09	0.04	ND	-	ND	-
Louisiana	1,316.0	13	1	0.11	-	0.38	-	0.03	-	X	-	ND	-
Florida	472.8	0	8	0.01	X	0.09	0.10	0.12	0.15	X	X	0.02	0.02
Florida	581.3	1	11	0.02	0.01	0.22	0.26	0.14	0.13	X	0.01	0.06	0.07
Florida	745.8	2	4	0.03	X	0.11	0.12	0.09	0.14	X	X	0.01	0.01
Florida	853.8	3	5	0.04	X	0.16	0.10	0.13	0.14	X	X	0.12	0.02
Florida	807.0	4	2	0.04	X	ND	-	0.04	X	ND	-	ND	-
Florida	918.0	5	2	0.05	0.01	0.11	0.06	0.01	0.01	-	-	0.02	0.03
Florida	996.0	6	1	0.05	-	0.33	-	0.05	-	X	-	0.01	-
Florida	1,080.0	8	1	0.06	-	0.75	-	0.06	-	ND	-	ND	-
North Carolina	704.5	1	4	0.02	X	0.35	0.22	0.05	0.01	X	X	0.02	0.01
North Carolina	741.3	2	4	0.03	X	0.27	0.13	0.19	0.05	X	X	X	X
North Carolina	810.8	3	4	0.03	X	0.49	0.35	0.04	0.04	ND	-	X	X
North Carolina	-----	4	2	0.06	X	0.50	0.30	0.15	0.10	ND	-	0.01	0.01
North Carolina	901.3	6	4	0.04	X	0.78	0.13	0.05	0.03	X	X	X	0.01
North Carolina	1,073.5	9	2	0.06	X	0.47	0.26	0.06	0.05	ND	-	ND	-
North Carolina	1,165.0	12	1	0.08	-	0.51	-	0.09	-	ND	-	ND	-

¹ X = Value less than .005² - = No data³ ND = Not detectable

mackerel (Fig. 1). The maximum concentrations of all metals in the otoliths were found in the smaller fish.

The major accumulation of metals occur in the very early stages in the life of fish. Organic matter is also principally concentrated in the center of the otolith (Dannevig 1956). Gauldie and Nathan (1977) postulate, from their work on the tarakihi, that the metal concentration of the otoliths may be largely concentrated in the nucleus. Daily growth increments in pike (*Esox mordax*) observed by Brothers, Mathews and Lasker (1976) begins just after the absorption of the yolk-sac. These increments provide the mechanism for the permanent deposition of the metals in the nucleus.

Uptake of any metals in later years is thought to be concealed by the addition of the growth increments of protein and aragonite crystals; however, substantial annual variations appear possible if the metals are available in the environment for uptake. Large variations of metal uptake in various tissues of fish appear to be related to environmental differences in the various fishing grounds (Cross, Hardy, Jones and Barber 1973).

The usefulness of metal content of otoliths as an indicator of age and origin of fish is suggested by our results from this king mackerel study. However a more sensitive procedure such as x-ray fluorescence spectrometry and the

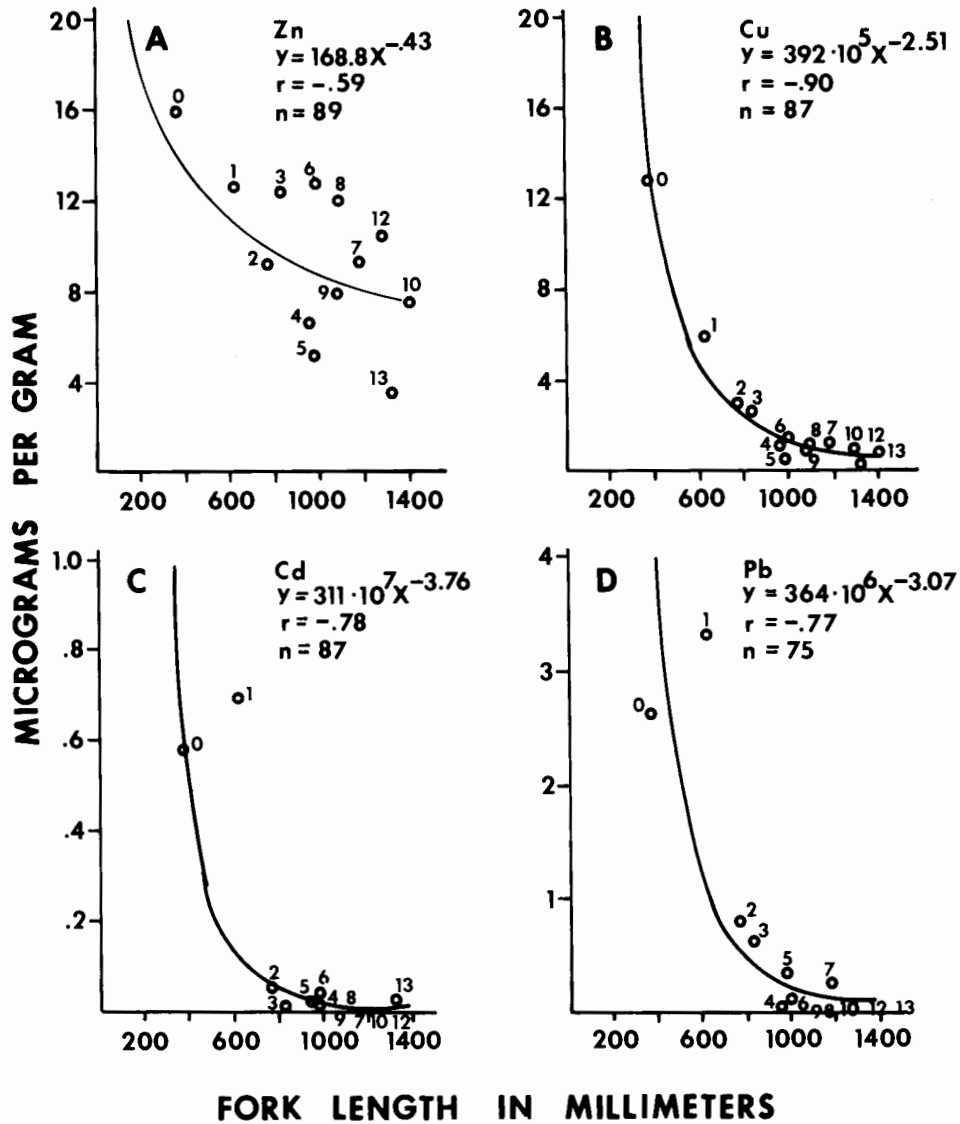


FIG. 1. Relationship between mean heavy metal concentration in otoliths and mean fork lengths of king mackerel.

- (A) zinc
- (B) copper
- (C) cadmium
- (D) lead

Numbers in figure are age in years at mean fork length.

examination of the internal structure of the otoliths is warranted (see Calaprice, McShaffrey and Lapi 1971 and Lapi and Mulligan 1981 for reviews of this approach).

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